Aspects of Diffraction at the Tevatron

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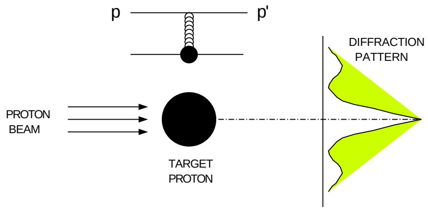
- Introduction
- Soft Diffraction
- Hard Diffraction
- Conclusion

Selected reviews: hep-ex/0011059, hep-ex/0011060, hep-ph/0205141, hep-ph/0203217

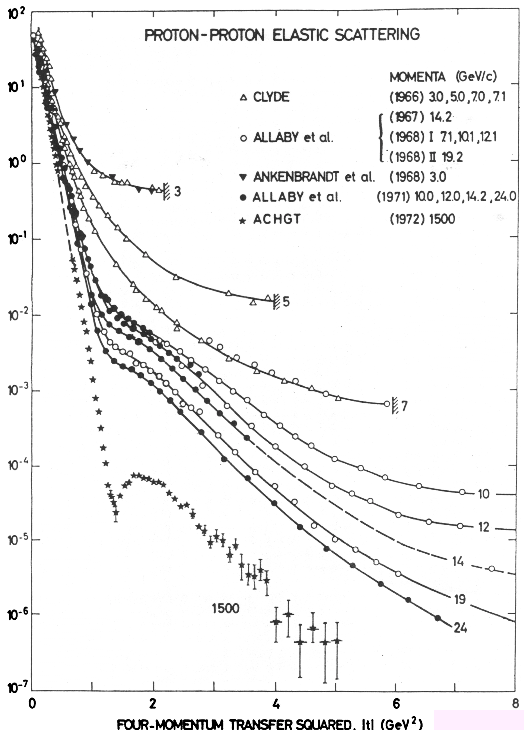
Introduction

What is hadronic diffraction?

PROTON-PROTON ELASTIC SCATTERING

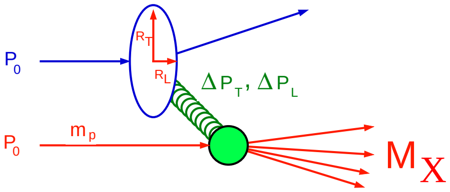


$$\frac{d\sigma}{dt}$$



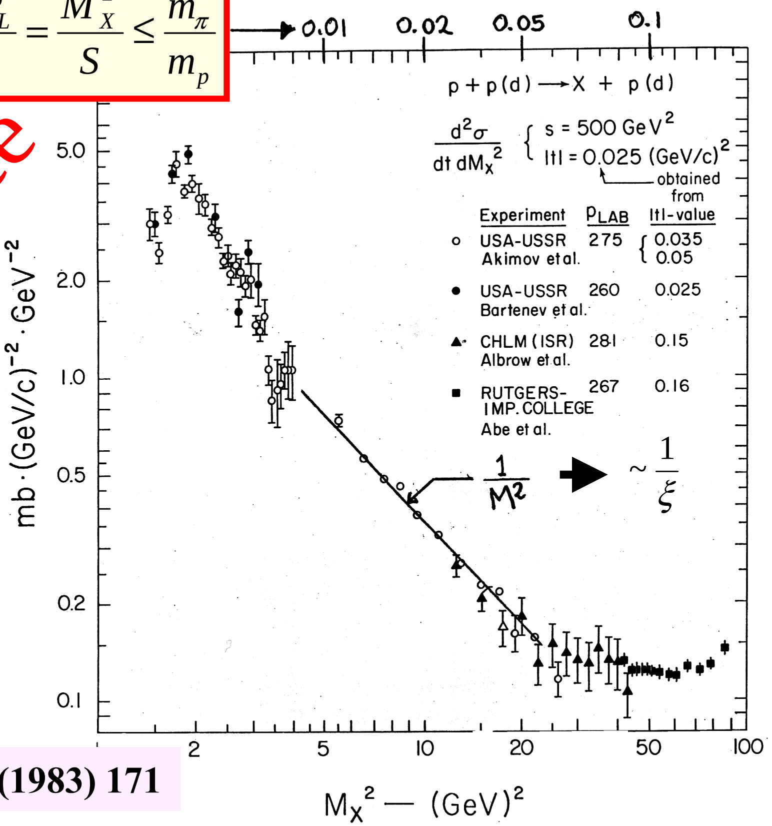
coherence

Diffraction dissociation



$$\xi = \frac{\Delta P_L}{P_L} = \frac{M_X^2}{S} \leq \frac{m_\pi}{m_p}$$

$$\frac{d^2\sigma}{dt\, dM^2}$$



KG, Phys. Rep. 101 (1983) 171

Diffraction and Rapidity Gaps

✓rapidity gaps are regions of rapidity devoid of particles

❑ **Non-diffractive interactions:**
rapidity gaps are formed by multiplicity fluctuations

From Poisson statistics:

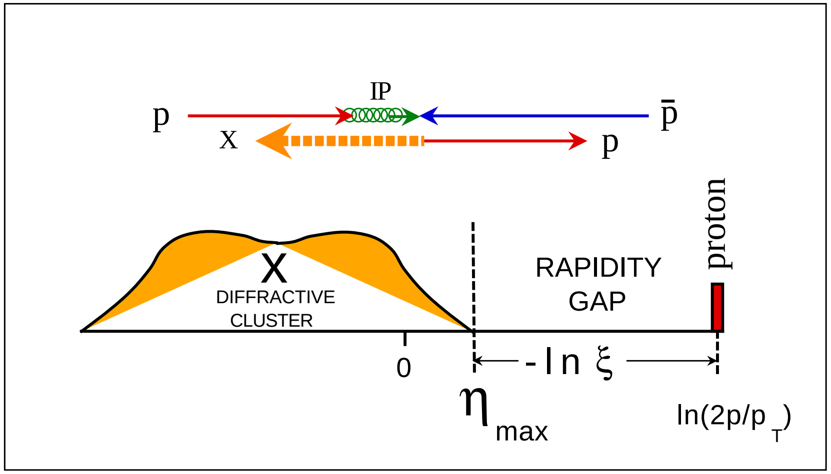
$$P(\Delta\eta) = e^{-\rho\Delta y} \quad \left(\rho = \frac{dn}{dy}\right)$$

(ρ=particle density in rapidity space)

Gaps are exponentially suppressed

❑ **Diffractive interactions:**
rapidity gaps, like diamonds, 'live for ever'

$$\Delta y \approx -\ln \xi = \ln s - \ln M^2$$



$$\frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \quad \rightarrow \quad \frac{d\sigma}{d\Delta y} \sim \text{constant}$$

✓ large rapidity gaps are signatures for diffraction

The Pomeron

- **Quark/gluon exchange across a rapidity gap:**

  POMERON

- **No particles radiated in the gap:**

  the exchange is COLOR-SINGLET with quantum numbers of vacuum

- **Rapidity gap formation:**

  NON-PERTURBATIVE

- **Diffraction probes the large distance aspects of QCD:**

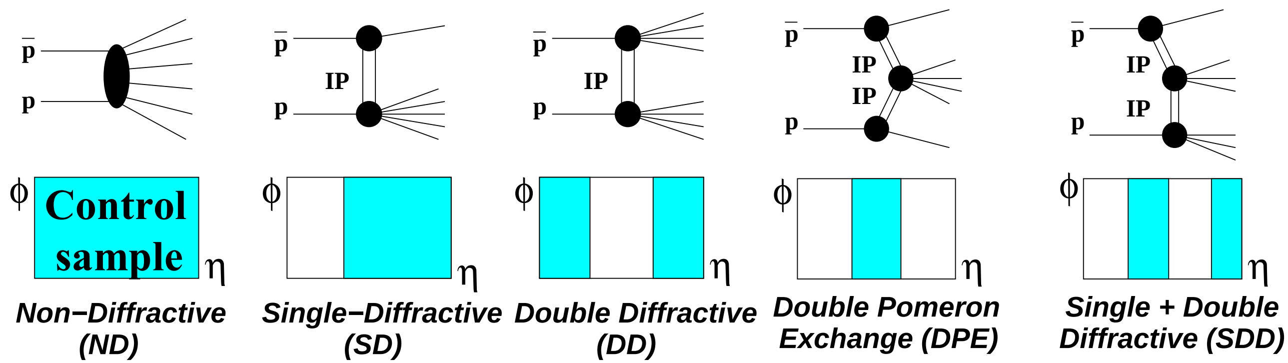
  POMERON ⟷ ? CONFINEMENT

  - **PARTONIC STRUCTURE**
  - **FACTORIZATION**

Diffraction at CDF in Run I

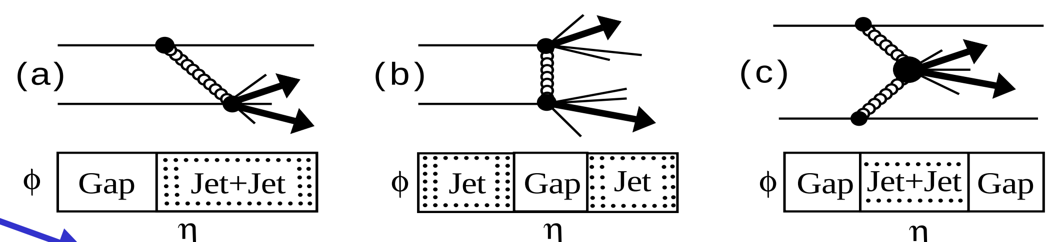
- Elastic scattering **PRD 50 (1994) 5518**
- Total cross section **PRD 50 (1994) 5550**
- Diffraction

SOFT diffraction



SD	DD	DPE	SDD
PRD 50 (1994) 5535	PRL 87 (2001)141802	PRL to be sub'd	PRL submitted

HARD diffraction



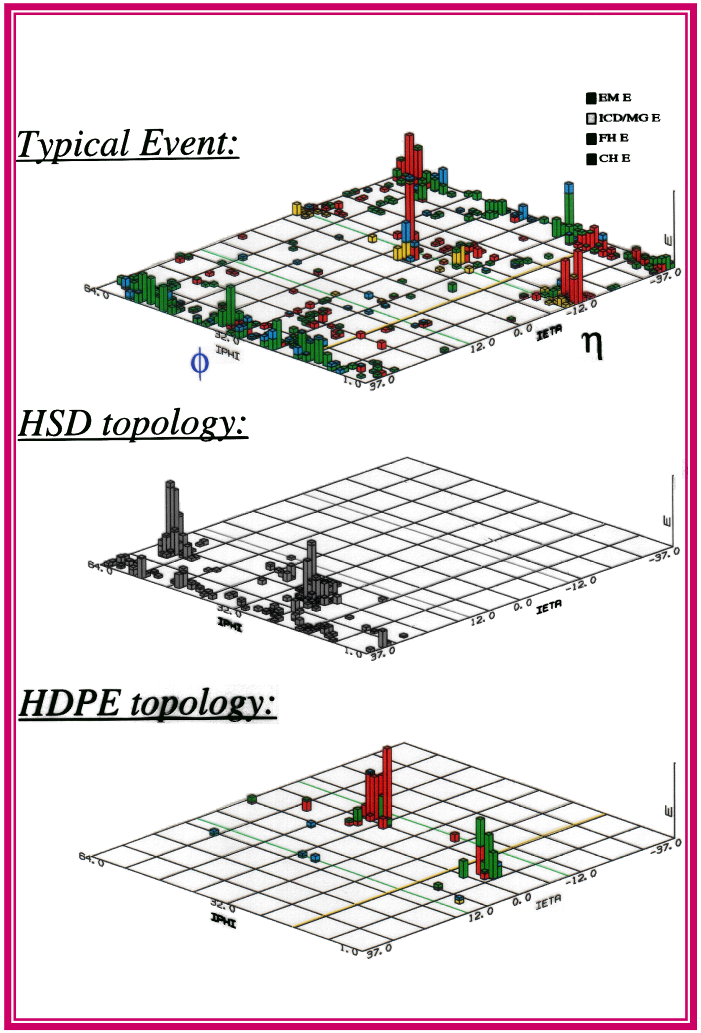
PRL reference

with roman pots

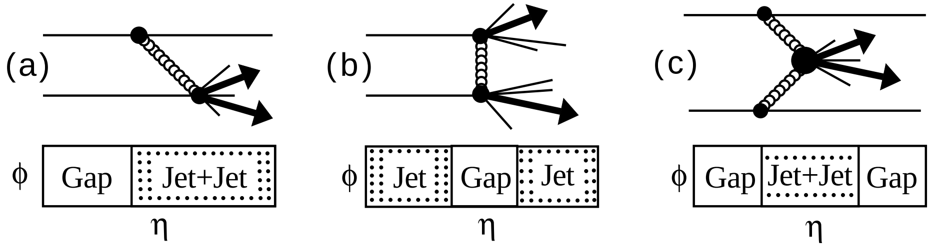
JJ	84 (2000) 5043
JJ	88 (2002) 151802

W 78 (1997) 2698	JJ 74 (1995) 855	JJ 85 (2000) 4217
JJ 79 (1997) 2636	JJ 80 (1998) 1156	
b-quark 84 (2000) 232	JJ 81 (1998) 5278	
J/ψ 87 (2001) 241802		

Diffraction at D0 in Run I



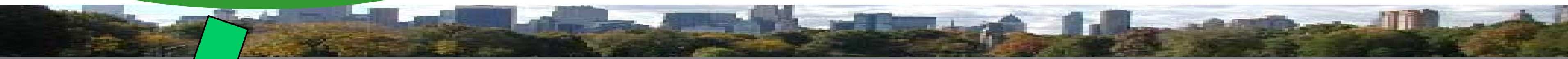
Hard diffraction



PLB 531(2002)52	PRL 72(1994)2332	Conference report
W-conf. report	PRL 76(1996)734	
	PRB 440(1998)189	

parton model

Soft diffraction

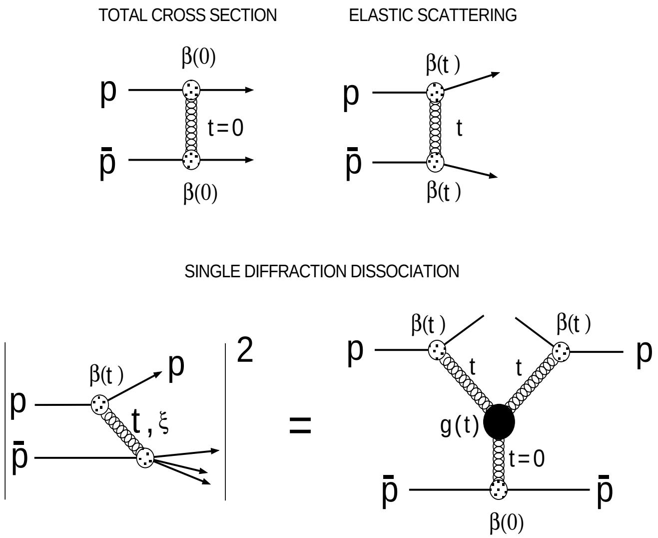


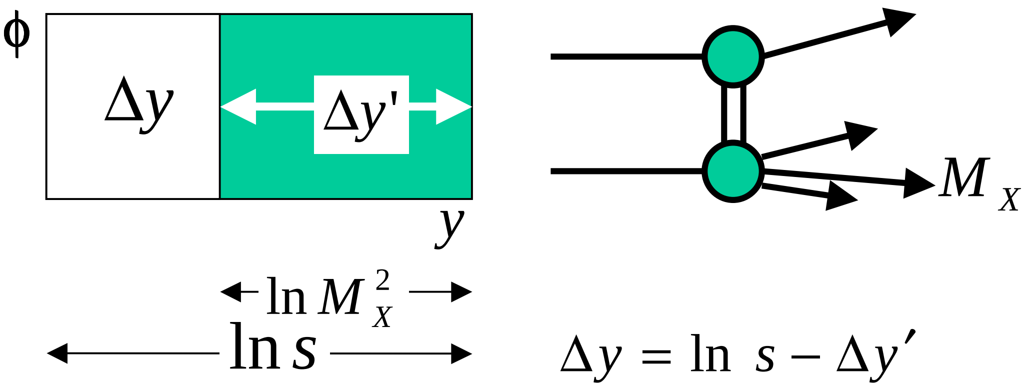
Factorization & Renormalization

$$\sigma_T = \sigma_o s^{\varepsilon} = \sigma_o e^{\varepsilon \ln s} = \sigma_o s^{\alpha_{IP}(0)-1}$$

$$\alpha_{\rm IP}(t) = 1 + \varepsilon + \alpha' t$$

Pomeron trajectory





$$\Delta y = \ln s - \Delta y'$$

$$\frac{d^2\sigma}{d\Delta y'\, dt} = f_{IP/p}(\Delta y, t) \times \sigma_{IP-p}(\Delta y')$$

$$C \cdot \left(e^{[\varepsilon + \alpha' t]\Delta y} F_p(t)\right)^2 \qquad \kappa \times \sigma_o e^{\varepsilon \Delta y'}$$

Renormalize to unity
KG, PLB 358(1995)379

Gap probability

$$\kappa = \frac{g_{IP-IP-IP}(t)}{\beta_{IP-p}(0)}$$

COLOR FACTOR

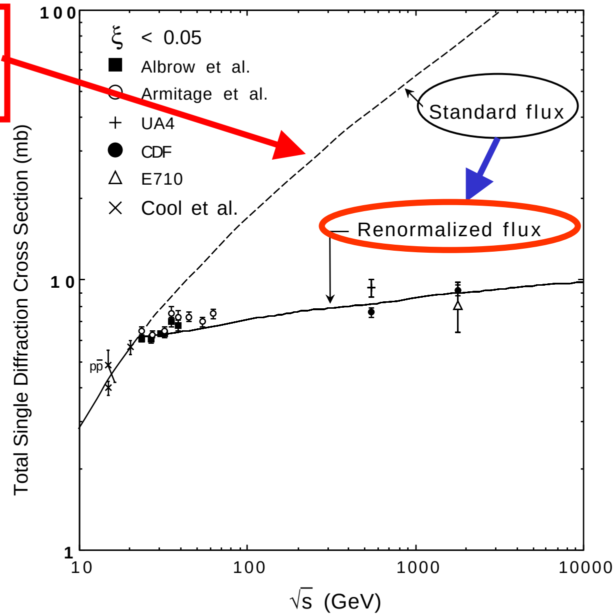
Soft Single Diffraction (CDF-I)

$$p(\bar{p}) + p \rightarrow p(\bar{p}) + X$$

$$\sigma \propto s^{2\varepsilon}$$

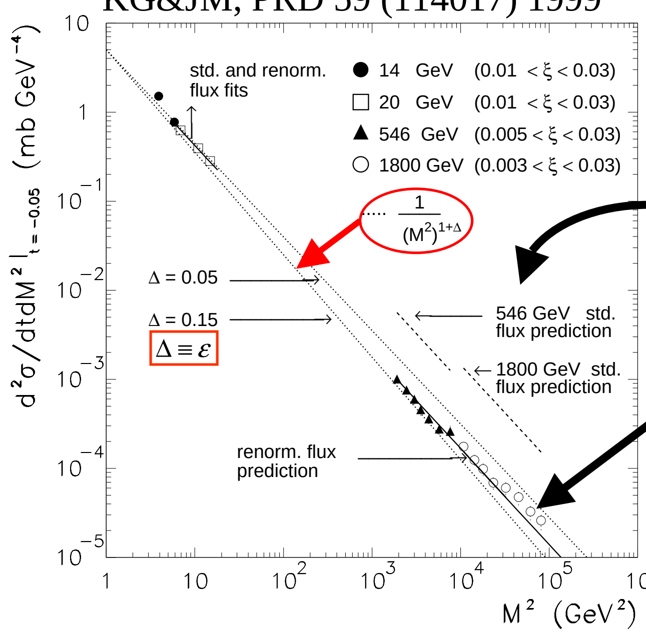
Total cross section

KG, PLB 358 (1995) 379



Differential cross section

KG&JM, PRD 59 (114017) 1999



REGGE

$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon}}{(M^2)^{1+\varepsilon}}$$

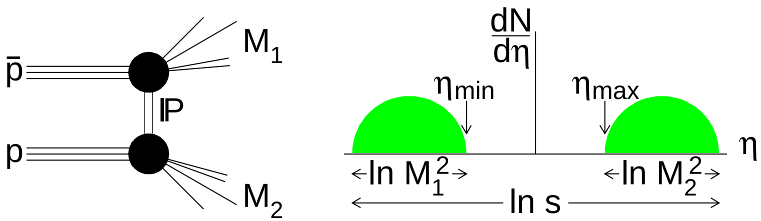
RENORM

$$\frac{d\sigma}{dM^2} \propto \frac{1}{(M^2)^{1+\varepsilon}}$$

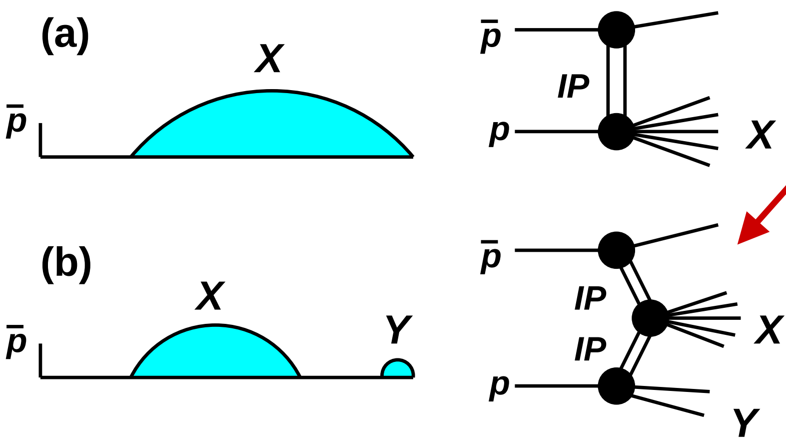
s-independent

- Differential shape agrees with Regge
- Normalization is suppressed by factor $\propto S^{2\varepsilon}$
- Renormalize Pomeron flux factor to unity → M^2 SCALING

Central and Double Gaps (CDF-I)



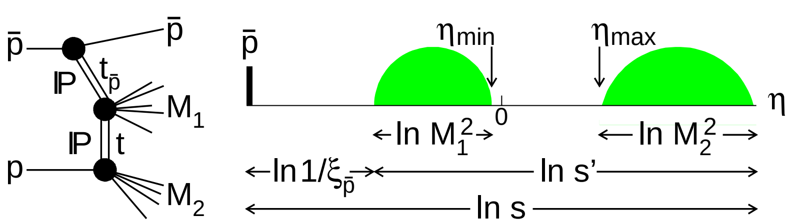
- **Double Diffraction**
- **Measure #Events versus Δη**



❑ **Double Pomeron Exchange**

➢ **Measure** $$\xi_p = \frac{1}{\sqrt{s}} \sum_{\text{all particles}} E_T^i \cdot e^{\eta_i}$$

➢ **Plot #Events versus log(ξ)**

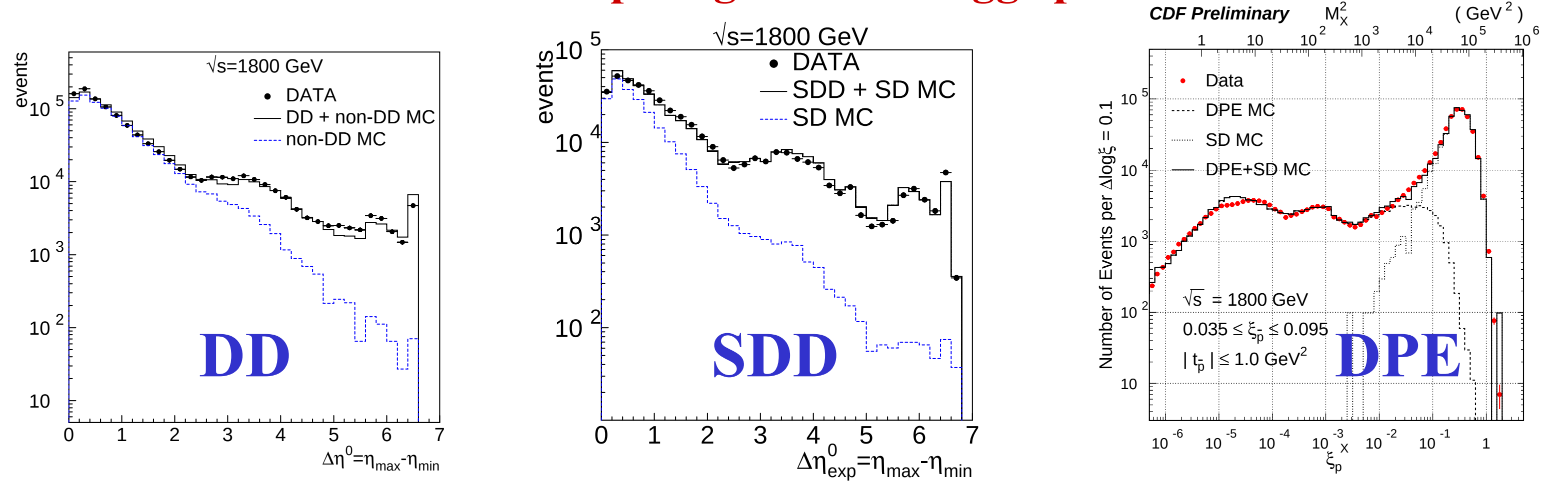


❑ **SDD: single+double diffraction**

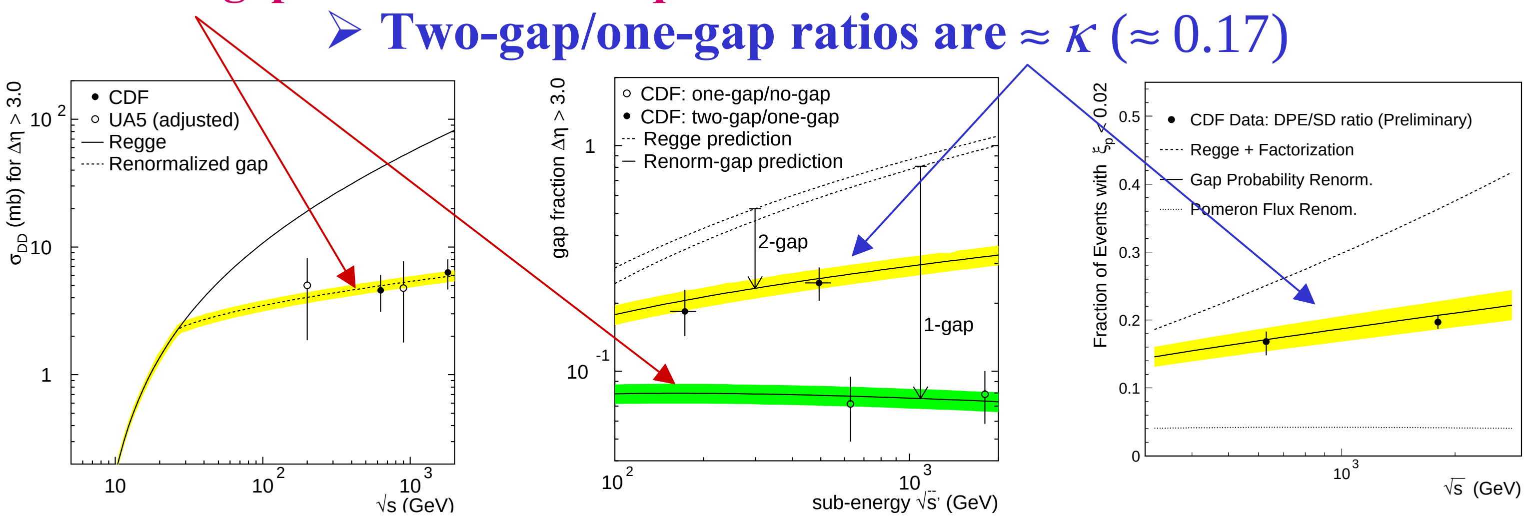
➢ **Central gaps in SD events**

Central and Double-gap Results (CDF)

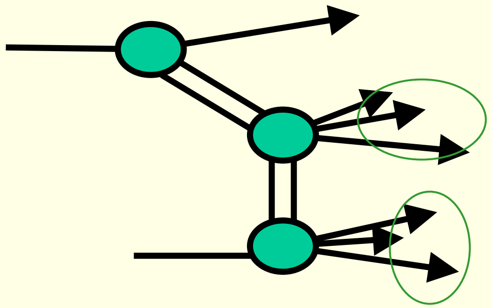
Differential shapes agree with Regge predictions

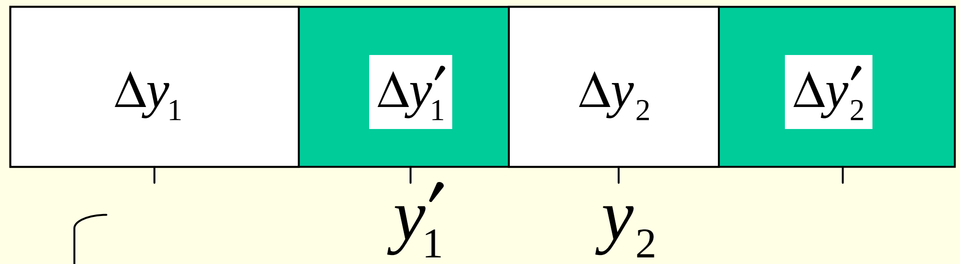


- **One-gap cross sections require renormalization**
  - **Two-gap/one-gap ratios are ≈ κ (≈ 0.17)**



Two-gap Diffraction (hep-ph/0205141)





5 independent variables $\left\{ \; y'_1, \; y_2, \; t_1, \; \Delta y = \Delta y_1 + \Delta y_2, \; t_2 \right.$

color factor

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = C \times F_p^2(t_1) \prod_{i=1-2} \left\{ e^{(\varepsilon + \alpha' t_i)\Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o \, e^{\varepsilon(\Delta y'_1 + \Delta y'_2)} \right\}$$

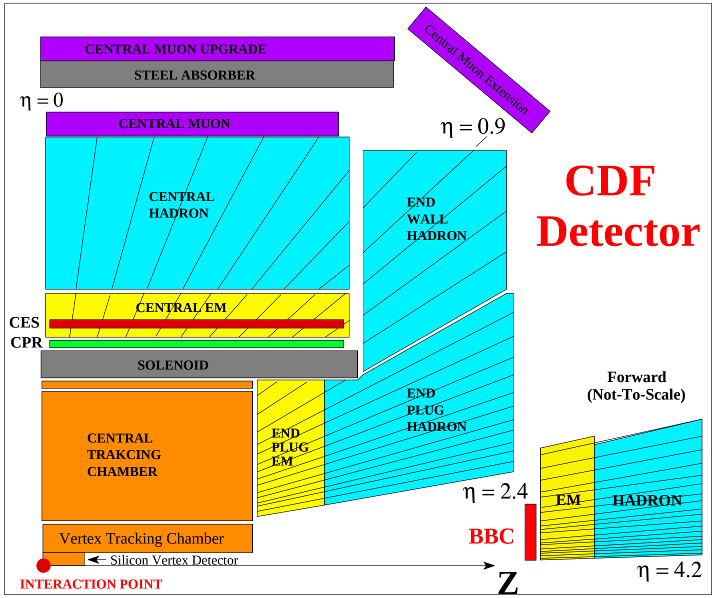
Gap probability

Sub-energy cross section (for regions with particles)

Integral $\sim s^{2\varepsilon}$ ← $\sim e^{2\varepsilon \Delta y}$

Renormalization removes the s-dependence → SCALING

Hard diffraction (Run I)



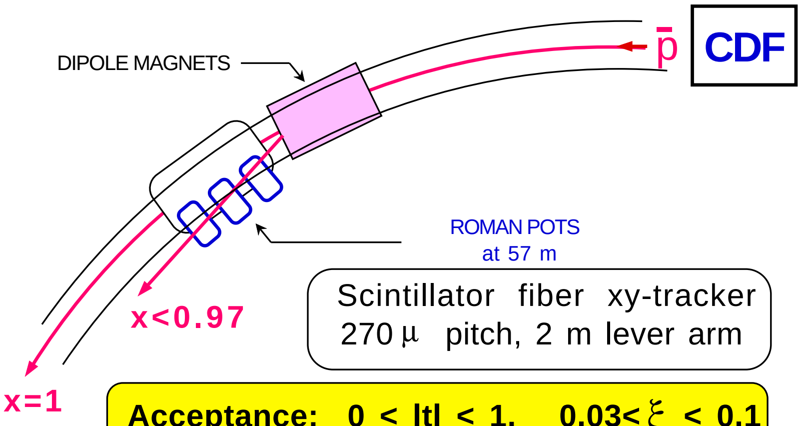
CDF Detector

Tag rapidity gaps

Tag antiproton

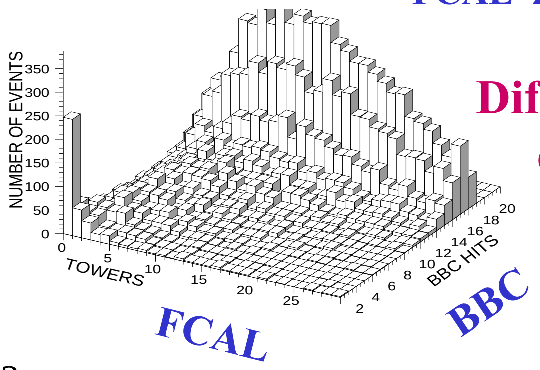
BBC $3.2<\eta<5.9$

FCAL $2.4<\eta<4.2$



Scintillator fiber xy-tracker
270 μ pitch, 2 m lever arm

Acceptance: 0 < |t| < 1, 0.03< ξ < 0.1



Diffractive dijets

Hard Diffraction Using Rapidity Gaps

❑ SINGLE DIFFRACTION

$$\bar{p}p \rightarrow X + \text{gap}$$

SD/ND gap fraction (%) at 1800 GeV

X	CDF	D0
W	1.15 (0.55)	
JJ	0.75 (0.10)	0.65 (0.04)
b	0.62 (0.25)	
J/ψ	1.45 (0.25)	

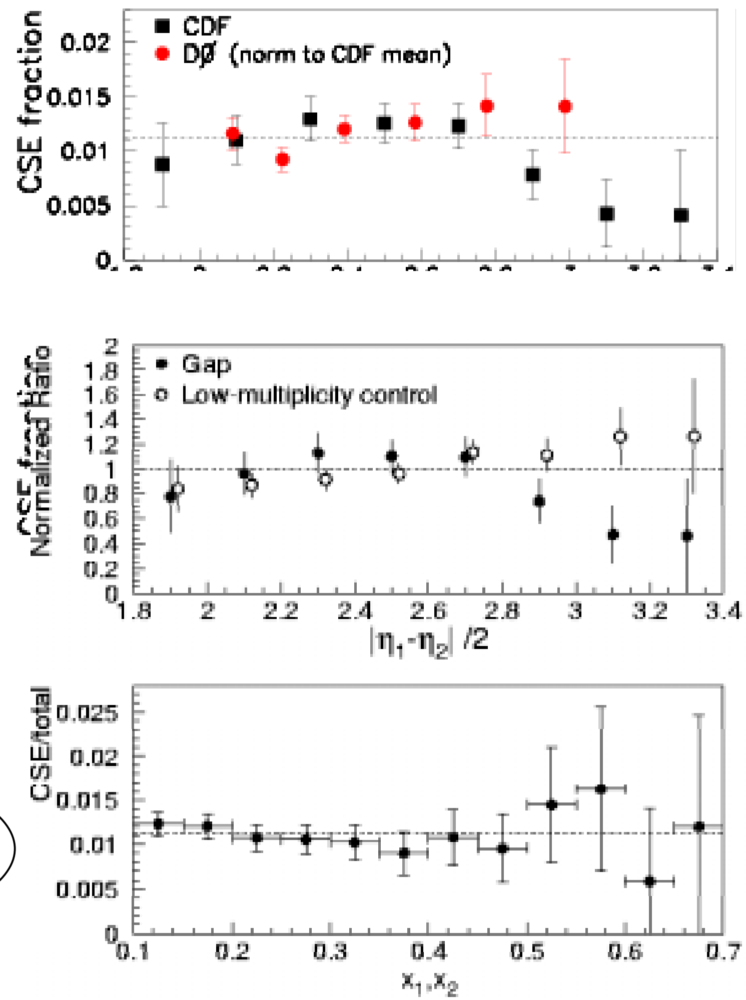
- **All SD/ND fractions ~1%**
- **Gluon fraction** $f_g = 0.54 \pm 0.15$
- **Suppression by ~5 relative to HERA**

Just like ND except for the suppression due to gap formation

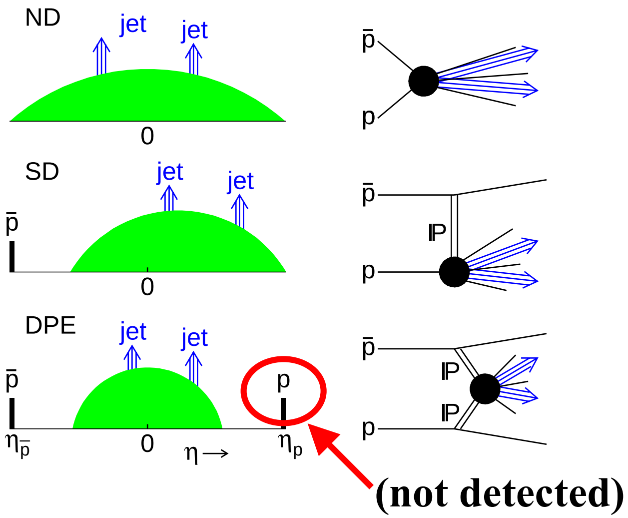
❑ DOUBLE DIFFRACTION

$$\bar{p}p \rightarrow Jet - \text{gap} - Jet$$

DD/ND gap fraction at 1800 GeV



Diffractic Dijets with Leading $\bar{p}$ (CDF)



$x_{Bj}^{\bar{p}}$ **Bjorken-x of antiproton**

$$x_{Bj}^{\bar{p}} = \frac{1}{\sqrt{s}} \sum_{\# jets} E_T^i \, e^{-\eta^i}$$

$F^{ND}(x, Q^2)$ **Nucleon structure function**

$F^{SD}(\xi, t, x, Q^2)$ **Diffractive structure function**

ISSUES: **1) QCD factorization** > $F^{SD}(\xi, t, x, Q^2)$ **is F^{SD} universal?**

2) Regge factorization > $F^{SD}(\xi, t, \beta, Q^2) = f_{IP-\text{flux}}(\xi, t) \times f_{IP}(\beta, Q^2)$ **?**

$\beta \equiv x/\xi$ **momentum fraction of parton in *IP***

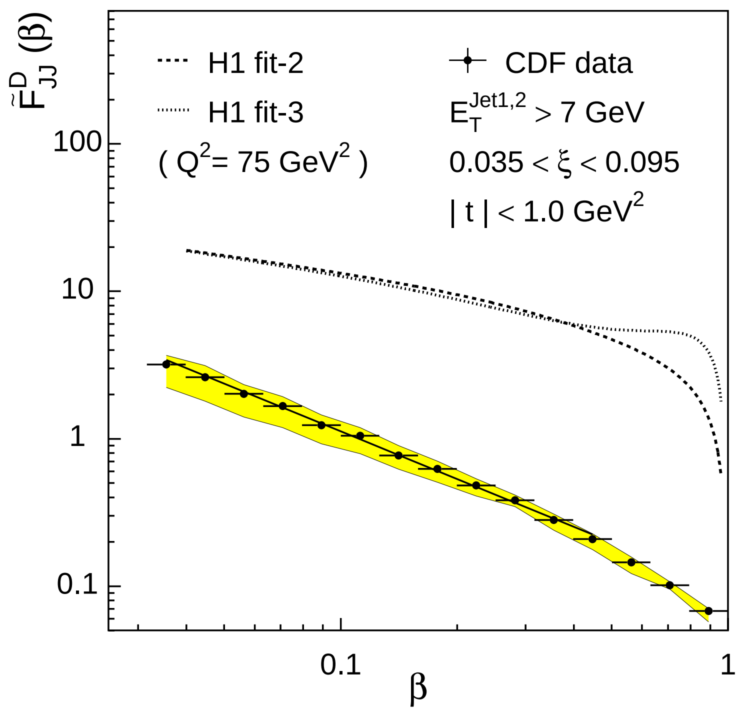
METHOD of measuring F^{SD} : measure ratio $R(\xi,t)$ of SD/ND rates for given ξ,t

set $R(\xi,t)=F^{SD}/F^{ND}$

evaluate $F^{SD} = R * F^{ND}$

Dijets in Single Diffraction (CDF-I)

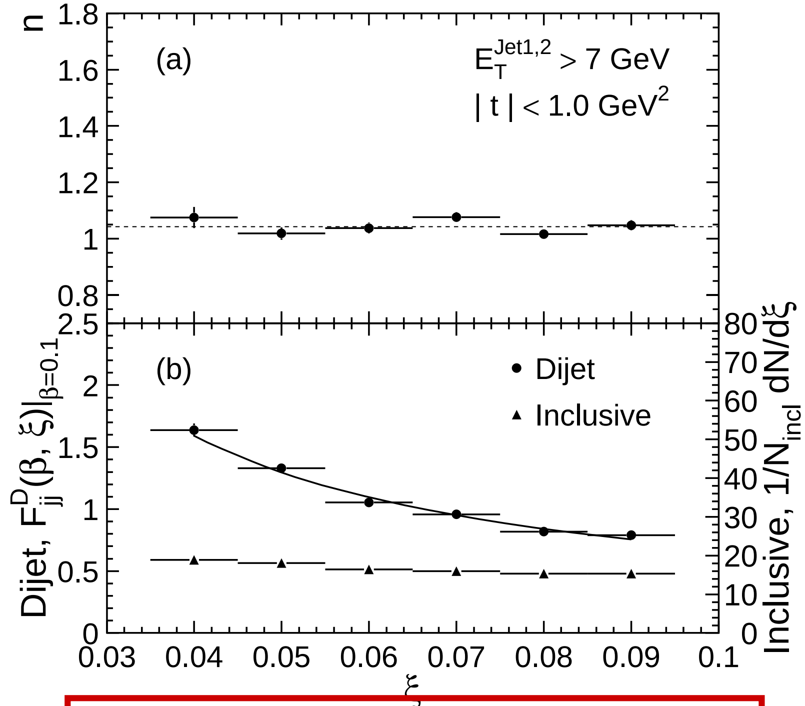
Test QCD factorization



$$F^{D}_{JJ}(\beta)$$

Suppressed at the Tevatron relative to predictions based on HERA parton densities

Test Regge factorization



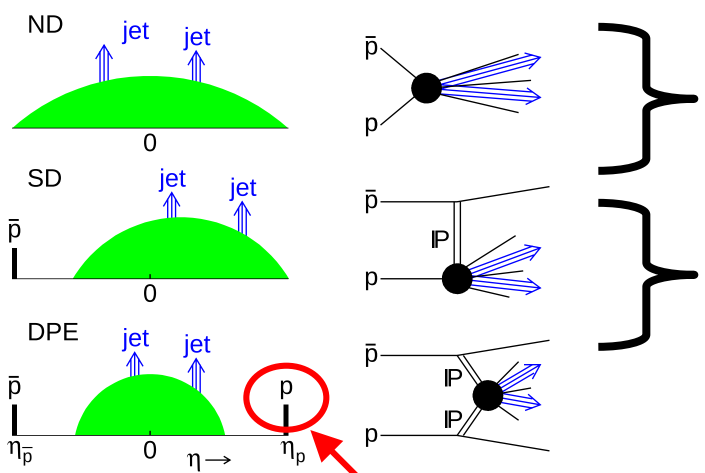
$$F^{D}_{JJ}(\xi, \beta) = C\ \beta^{-n}\ \xi^{-m}$$

Regge factorization holds

$m \approx 1 \Rightarrow$ Pomeron exchange **!!!**

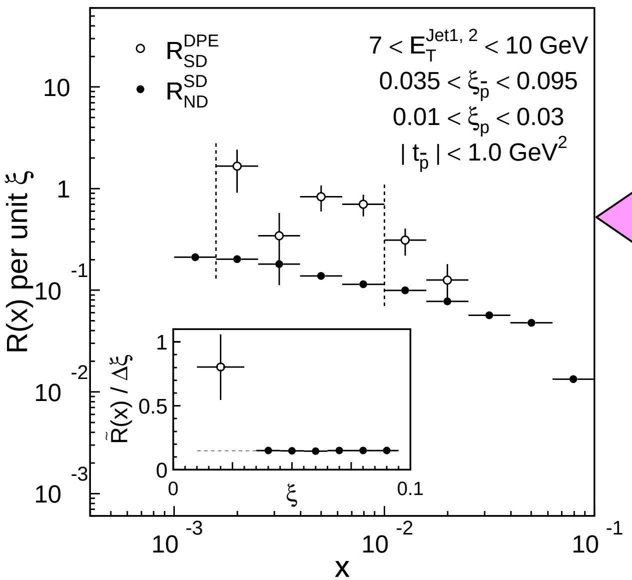
Dijets in Double Pomeron Exchange (CDF-I)

Test of factorization



equal?

(not detected)



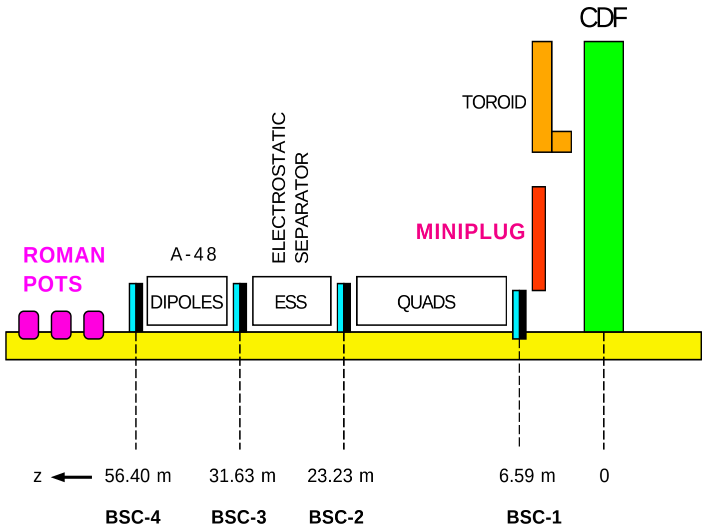
$$R_{SD}^{DPE} \approx 5 \times R_{ND}^{SD}$$

Factorization breaks down

The second gap is un-suppressed!!!

Run II Diffraction at the Tevatron

CDF and D0 Forward Detectors



- ✓ **MiniPlug calorimeters (3.5<η<5.5)**
- ✓ **Beam Shower Counters (5.5<η<7.5)**
- ✓ **Antiproton Roman Pot Spectrometer**

- ❑ **Roman Pot Spectrometers on proton & antiproton sides**

Run II Data Samples (CDF)

Triggers

J5	At least one cal tower with ET > 5 GeV
RP inclusive	Three-fold coincidence in RP trigger counters
RP+J5	Single Diffractive dijet candidates
RP+J5+BSC-GAP_p	Double Pomeron Exchange dijet candidates

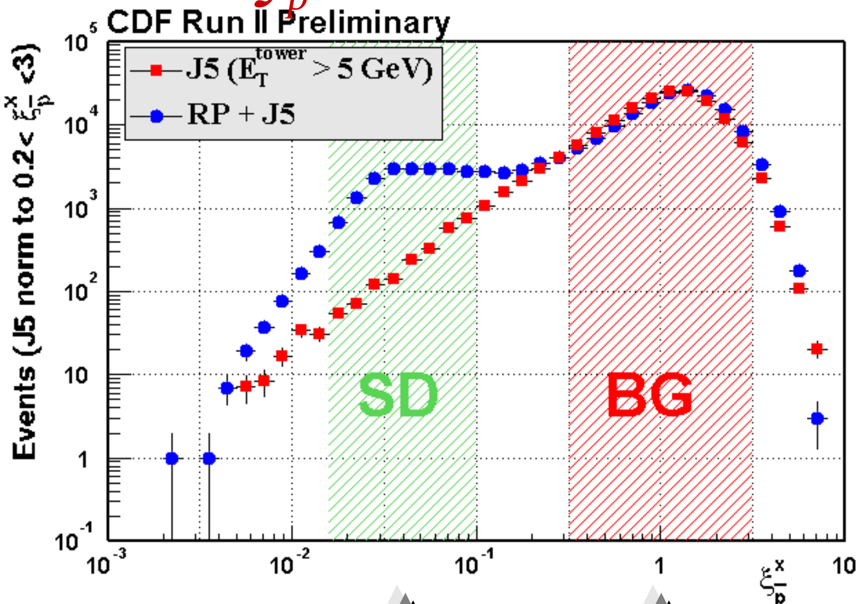
- Results presented are from ~26 pb^{-1} of data
- The Roman Pot tracking system was not operational for these data samples
- The ξ of the (anti)proton was determined from calorimeter information:

$$\xi = \frac{1}{\sqrt{s}} \sum_{\text{cal towers}} E_T^i \, e^{(-)+\eta^i}$$

(-)+ is for (anti)proton

Run II Dijets in Single Diffraction (CDF)

$\xi_{\bar{p}}^{X} - distribution$



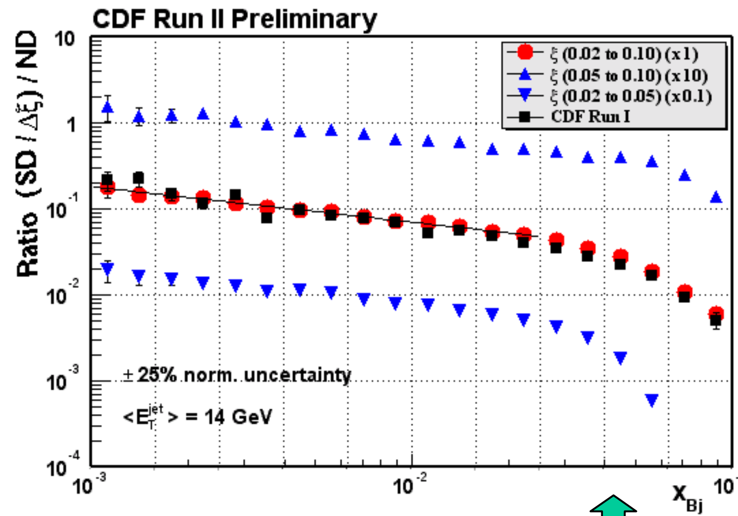
SD events

0.03<ξ<0.1

ND+SD & SD+MB overlap events

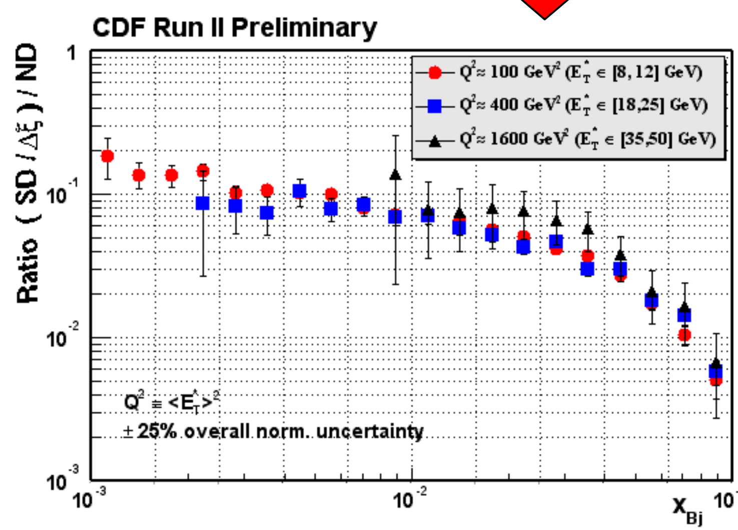
ξ ~ 1

R=(SD/Δξ)/ND



Agreement with Run I

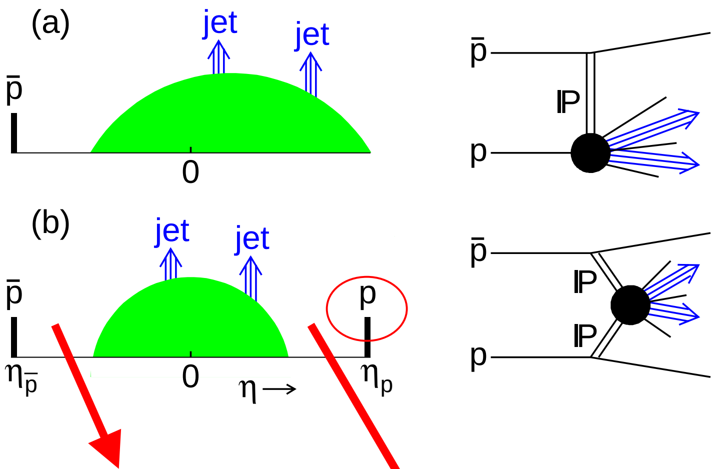
No Q2 dependence

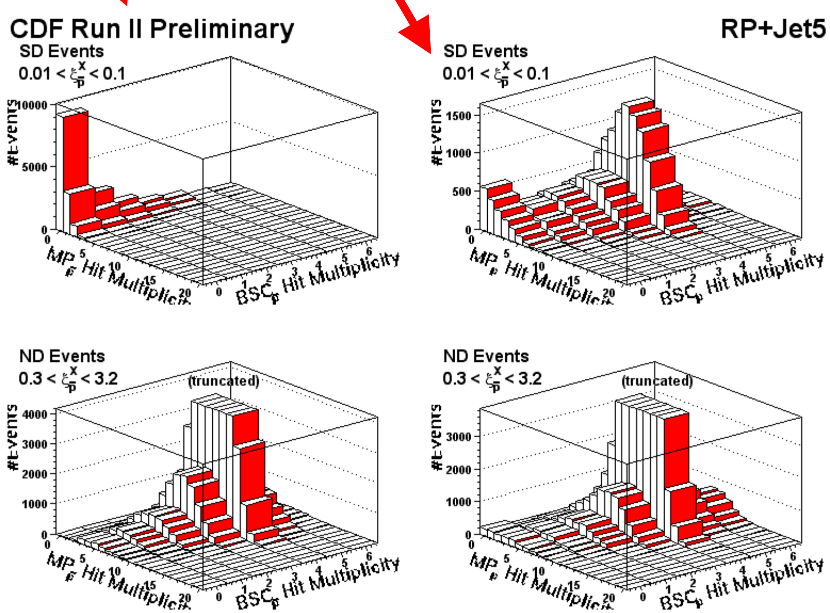


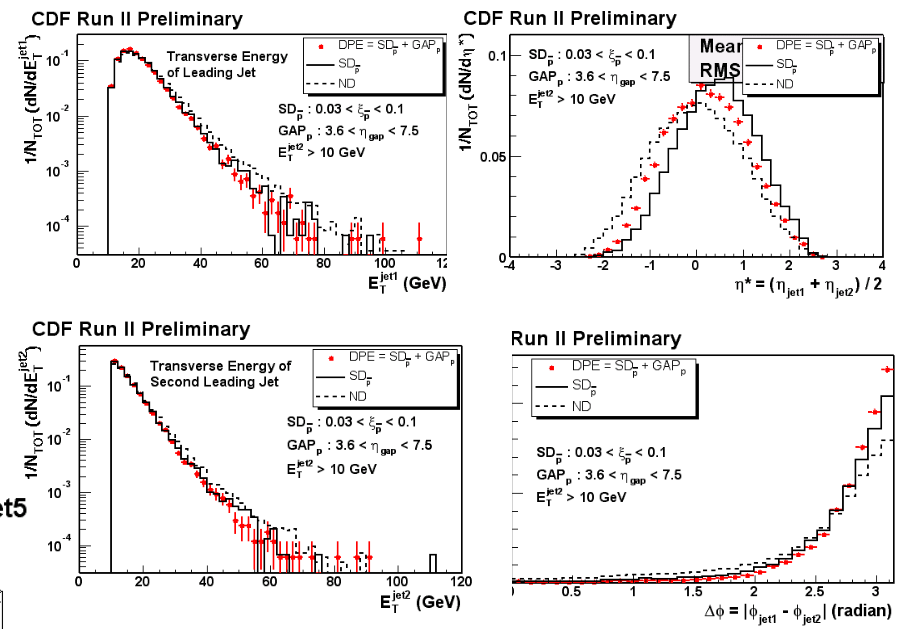
Flat region

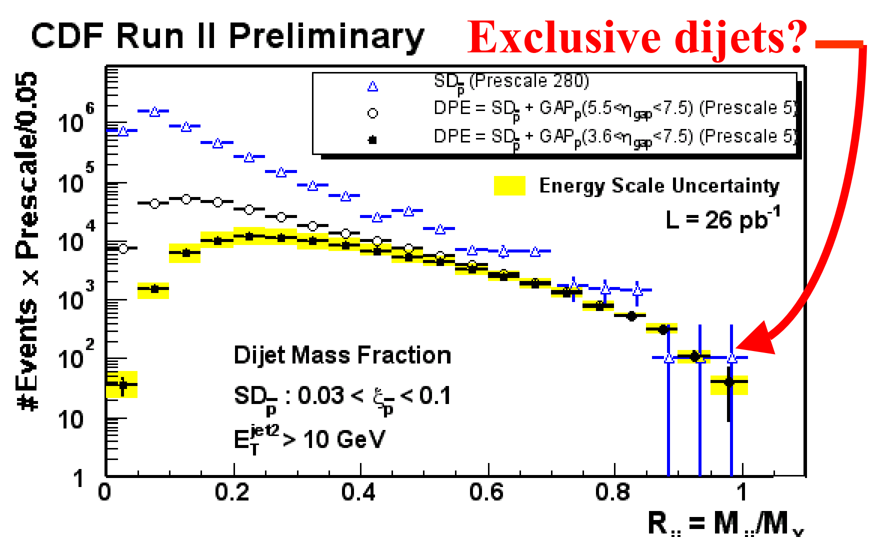
$$\frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{d\log\xi} = \text{constant}$$

Run II Dijets in DPE (CDF)

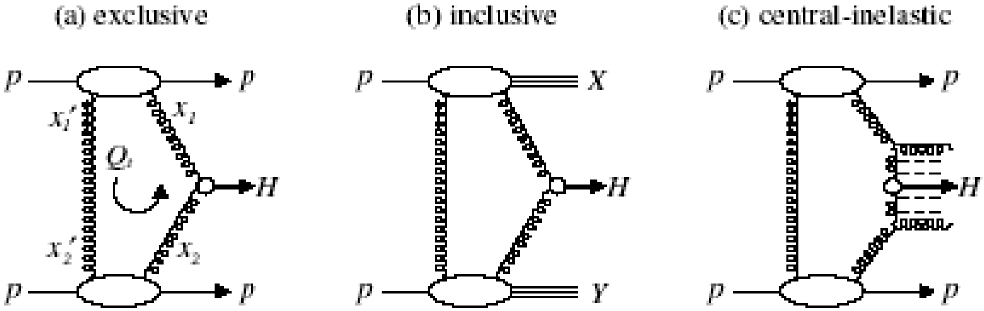




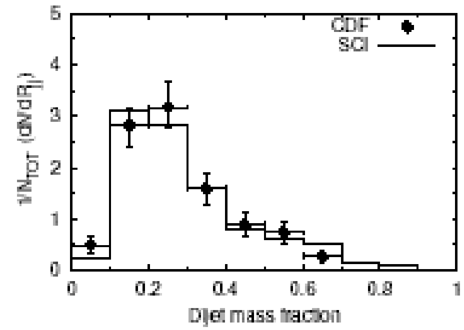




Inclusive/Exclusive DPE Dijet Predictions



Khoze, Martin, Ryskin
Eur. Phys. J. C23, 211 (2001), C26, 229 (2002)

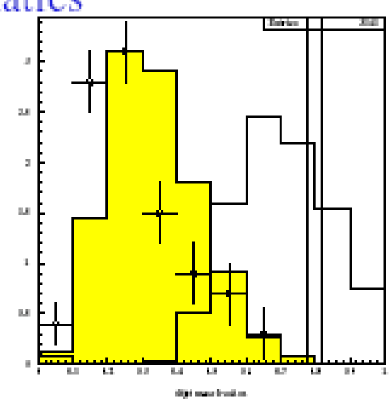


Enberg, Ingelman, Timneanu
Acta. Phys. Polon. B33, 3479 (2002)

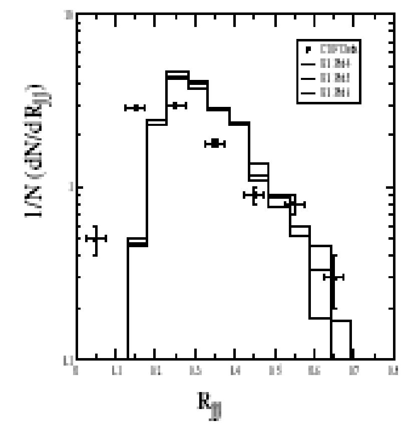
Exclusive dijets in Run I CDF kinematics
~ 1nb (factor 2 uncertainty)

Recent Calculation: ~ 60pb
($25<E_T^{jet}<35$ GeV, $|\eta_1-\eta_2|<2$)

Used to normalize calculations to predict e.g, diffractive Higgs production

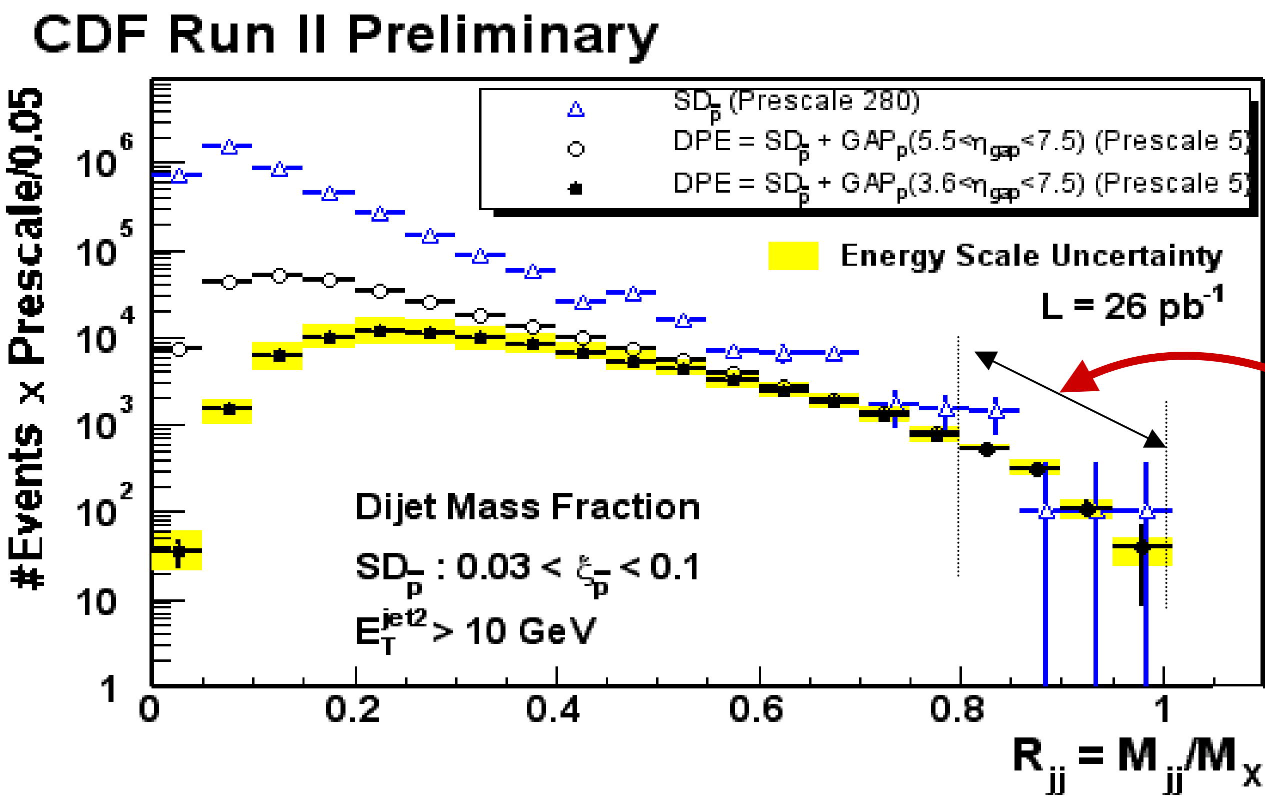


Boonekamp, Peschanski, Royon
Phys. Rev. Lett. 87, 251806 (2001)



Appleby, Forshaw
Phys. Lett. B541, 108 (2002)

Run II: Exclusive DPE Dijets ?



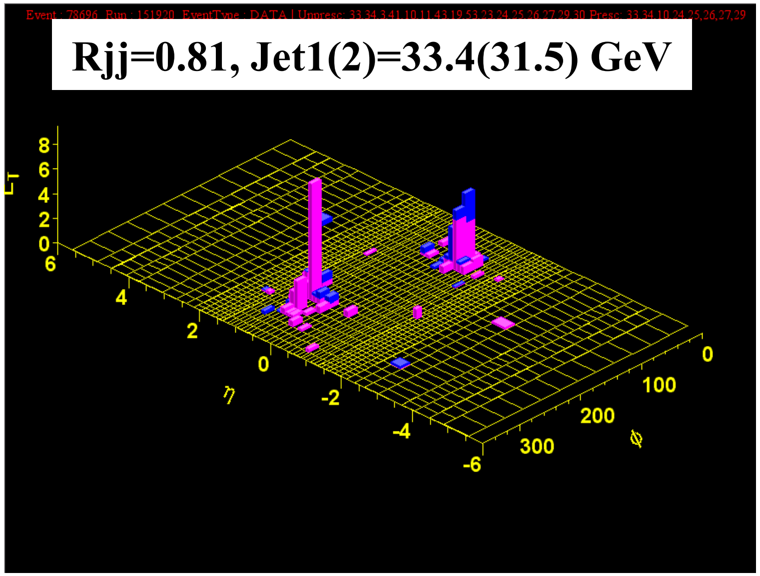
No exclusive dijet bump observed

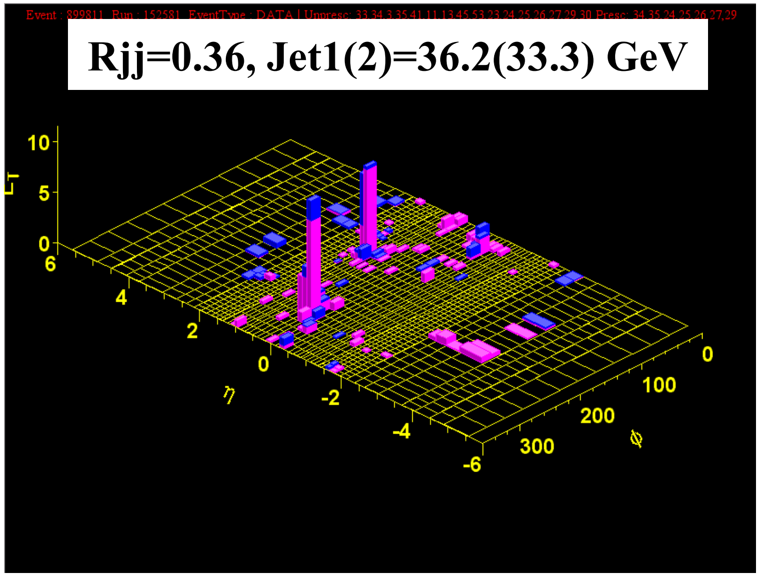
$|\eta_{jet1,2}|<2.5,\ 0.03<\xi_{\bar{p}}<0.1,\ 3.6<\eta_{gap}<7.5,\ R = 0.7$

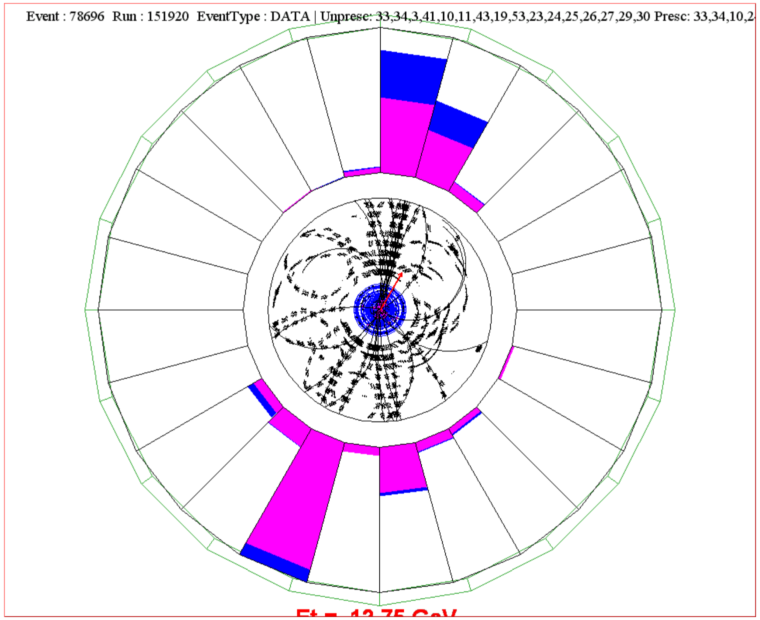
Minimum E_T^{jet1}	Cross Section : $\sigma_{DPE}^{excl.\ jj}(R_{jj}>0.8)$
10 GeV	970 ± 65(stat) ± 272(syst) pb
25 GeV	34 ± 5(stat) ± 10(syst) pb

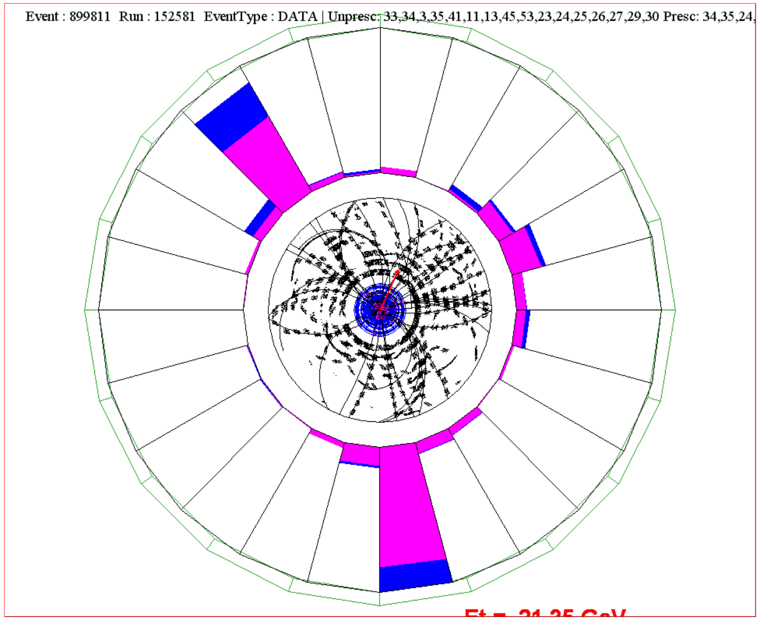
Generous upper limit on exclusive dijets

Double Pomeron Exchange Dijet Events









SUMMARY

Soft and hard conclusions

SOFT →

1) **Differential shapes agree with factorization based Regge predictions**
2) **Single-gap production rates are suppressed as the energy increases**
3) **Renormalizing the gap probability to unity yields correct rates**
4) **Two-gap to one-gap ratios are ~ equal to** $\kappa = g_{IP-IP-IP} / \beta_{IP-p}$ ← **COLOR FACTOR**

HARD → **Same general features as in soft diffraction**